Microlensing of Broad Absorption Line Quasars: Polarization Variability

Kunegunda E. Belle

Department of Physics and Astronomy, University of Wyoming, Laramie, WY 82071;
keb@tana.uwyo.edu

and

Geraint F. Lewis

Department of Physics and Astronomy, University of Victoria, Victoria, B.C., Canada;
gfl@uvastro.phys.uvic.ca; and
Astronomy Department, University of Washington, Seattle WA, U.S.A.;
gfl@astro.washington.edu

ABSTRACT

Roughly 10% of all quasars exhibit Broad Absorption Line (BAL) features which appear to arise in material outflowing at high velocity from the active galactic nucleus (AGN). The details of this outflow are, however, very poorly constrained and the particular nature of the BAL material is essentially unknown. Recently, new clues have become available through polarimetric studies which have found that BAL troughs are more polarized than the quasar continuum radiation. To explain these observations, models where the BAL material outflows equatorially across the surface of the dusty torus have been developed. In these models, however, several sources of the BAL polarization are possible. Here, we demonstrate how polarimetric monitoring of gravitationally lensed quasars, such as H 1413+117, during microlensing events can not only distinguish between two currently popular models, but can also provide further insight into the structure at the cores of BAL quasars.

Subject headings: Quasars: Absorption Lines — Quasars: Individual (H1413+117)

1. Introduction

While they are amongst the most luminous objects in the universe, the vast majority of the energy radiated by quasars arises in a region less than a parsec in extent. At cosmological distances, such a region subtends only microarcseconds and its structural properties are well below detection

by conventional techniques. A growing number of studies, however, have demonstrated that if such sources are microlensed by stars in a foreground system then observations during high magnification events can reveal details at these scales, probing both the structural and kinematic properties of quasars (Kayser, Refsdal, & Stabell 1986; Nemiroff 1988; Irwin et al. 1989; Schneider & Wambsganss 1990; Corrigan et al. 1991; Lewis et al. 1998).

Recent studies have extended this earlier work, providing further approaches by which microlensing can reveal the inner structure of quasars. Using the fact that, to a microlensing mass, the quasar continuum source appears quite extended, and that variations intrinsic to the source will be manifest in all the macrolensed images, Yonehara et al. (1998, 1999) demonstrated how the nature of the accretion disk can be probed with multi-wavelength observations. Accordingly, the size of the source may also be constrained by monitoring and studying quasar variations (Yonehara 1999), high-magnification event shapes (Wyithe & Webster 1999), and fold caustic crossing events (Fluke & Webster 1999). A different approach by Lewis & Ibata (1998) used the microlensing induced centroid shift of a macrolensed image to determine quasar structure.

In a previous paper, (Lewis & Belle 1998; hereafter Paper I), we demonstrated how microlensing may be used to examine the scale of the clouds responsible for the prominent BALs seen in some quasars. Here we extend this earlier study and show how spectropolarimetric monitoring of BAL quasars can provide further clues to the internal structure of quasars, specifically the details of the scattering mechanism responsible for the polarization increase observed within the BAL troughs. A description of the current favored models of BAL systems is presented in Section 2, while the rôle of microlensing as a probe of these models is discussed in Section 3. The statistics of microlensing events are presented in Section 4.2, focusing on the case of the multiply imaged quasar, H 1413+117. The conclusions of this study are presented in Section 5.

2. Broad Absorption Line Quasars: Models

About 10% of quasars display BALs in their spectra, appearing blue-ward of prominent emission lines and exhibiting bulk outflow velocities of $5000 - 30000$ km s^{-1}. These are generally interpreted as resonance absorption line systems due to highly ionized species (Turnshek 1984, 1988, 1995; Weymann 1995). The comparative rarity of BAL quasars has made them the focus of numerous studies and has led to the question of their place in the unified model of active galactic nuclei (e.g., Antonucci 1993), a question that is currently a matter of debate (Kuncic 1999).

The nature of the absorbing region responsible for these spectral features, although the subject of various investigations, has yet to be fully explained. Several different observations of BAL quasars are, however, beginning to paint a picture of the inner regions of the quasar and the material which produces the BALs. Abundance ratios indicate that the constant source of material could emanate from atmospheres of giant stars (Scoville & Norman 1995), novae (Shields 1996, 1997), parts of an inner obscuring torus or even parts of the accretion disk (Murray et al. 1995). The high outflow

velocity of the absorbing material, most likely due to radiative acceleration (Arav, Li, & Begelman 1994), has led to models which consider the necessary confinement of the clouds comprising the BAL region. Pressure confinement by a hot ambient medium (Arav, Li, & Begelman 1994) or by magnetic fields (Arav & Li 1994) and X-ray shielding of the material by a very high column density ionized gas (Murray et al. 1995) have all been offered as solutions to the confinement problem. Alternatively, the confinement problem can be avoided altogether by involving a continuous, high column density outflow of absorbing gas rather than clouds (Kuncic 1999). Electron column densities imply that the region lies at a distance of 30-500 pc from the central continuum source (Turnshek 1986). Estimates for the radial extent of the absorbing clouds range from 10^8 cm [assuming many clouds with small filling factors (Weymann 1995)] up to $10^{13.5}$ cm [from column density measurements (Turnshek 1995; Murray et al. 1995)] and even sizes as large as 10^{15} cm [determined from microlensing limits (Paper I)] have been suggested.

The 'blackness' of some of the observed troughs indicates that the material in the BAL region can completely obscure our view of a quasar core. This region typically possesses an angular scale of only microarcseconds, making a determination of the geometrical properties of the BAL region virtually impossible with normal observational techniques. It has become apparent, however, that our view of quasars in polarized light is implicitly dependent upon the geometry of the central regions. From the various polarimetry studies undertaken for BAL quasars, several consistent observations have been noted; it is seen that the broad emission lines evident in the quasar spectra exhibit no or very low net polarization (e.g., Goodrich & Miller 1995; Schmidt & Hines 1999), while it has also been shown that a greater amount of polarization exists in the BAL troughs ($\sim 12\%$) as compared to the continuum ($\sim 2\%$) (e.g., Cohen et al. 1995; Ogle 1997; Schmidt & Hines 1999). Other clues come from the amount of reddening seen in the broad emission lines, with $E(B-V) \sim 0.4$, which is significantly greater than that seen in the continuum or the BALs, with $E(B-V) > 0.1$ (Sprayberry & Foltz 1992).

The existence of polarized light in quasar spectra indicates that some scattering of radiation must be present. When the above observations are considered together, a schematic picture of the central regions of the BAL quasar emerges, with the material responsible for the BAL absorption being blown equatorially from the dusty torus surrounding the central accretion disk (e.g., Goodrich & Miller 1995; Hines & Wills 1995; Weymann 1995; Schmidt & Hines 1999). As illustrated in Figure 1, however, two possible configurations have been proposed to explain the observed polarization properties of BAL spectra (e.g., Cohen et al. 1995);

- **Model A:** The path of the continuum light (Path A) is a simple direct path which leaves the central source and passes through the BAL region. In this case, it is assumed that the continuum emission is intrinsically polarized upon leaving the source. As the radiation travels through the absorbing region, any polarization already present is enhanced by the action of resonance scattering of emission into the line of sight, leading to the BAL troughs exhibiting greater percentage polarization than the continuum.

- **Model B:** This model assumes a slightly more complex geometry in which emission from the continuum source is intrinsically unpolarized. This light travels not only directly to an observer, traversing the BAL region, but also along an alternate path (denoted B in Figure 1) impinging upon a scattering region, most likely consisting of electrons or dust (Antonucci & Miller 1985; Goodrich & Miller 1995; Gallagher et al. 1999; Brandt et al. 1999). It then travels on to an observer, leaving the central regions of the quasar without necessarily traveling through the BAL region. Unpolarized light coming directly to the observer dilutes this polarized flux in the continuum of the spectrum. The BAL troughs, however, eat into this unpolarized flux, reducing the dilution and enhancing the percentage polarization in the absorption line.

The goal of this paper is to demonstrate how photometric and polarimetric monitoring of microlensed BAL quasars can clearly delineate between the above proposed models, and illustrate how microlensing can give further clues to the nature of BAL quasars.

3. Microlensing

Chang and Refsdal (1979) first demonstrated that the granularity of galactic matter, distributed on small scales as point-like stars and planets, can exert a gravitational lensing influence on the light passing through it from a distant source. While the image splitting introduced by such masses is extremely small ($\sim 10^{-6}$ arcseconds), such lenses can induce a significant magnification of a background source. As the relative configuration of source, lensing stars, and observer change, so too does the degree of magnification and consequently the brightness of a background source is seen to fluctuate. Such fluctuations have been seen in the light curve of the quadruple quasar, Q 2237+0305 (Irwin et al. 1989; Corrigan et al. 1991).

The original work of Chang and Refsdal (1979) considered the gravitational lensing action of a single, isolated star [a description that accurately represents the simple gravitational lensing by MACHO objects within our Galactic halo (Alcock et al. 1993)], however, it is the case that many stars act on a light beam as it passes through a galaxy. In such a high optical depth regime, the pattern of magnification a source will suffer is no longer simple; rather it is characterized by a series of violent asymmetric fluctuations, inter-spaced with quiescent regions where the source suffers demagnification, also known as the microlensing caustic structure (Kayser, Refsdal, & Stabell 1986).

Different numerical techniques have been developed to investigate the pattern of magnification that a microlensed object undergoes. The backwards ray-tracing method, which reconstructs a map of magnification (Kayser, Refsdal, & Stabell 1986; Wambsganss 1990) and the contour algorithm (Lewis et al. 1993; Witt 1993) have proven to be useful in the analysis of the statistical properties of microlensed induced variability (Lewis & Irwin 1995, 1996).

To understand the characteristics of variability introduced by microlensing, it is necessary to determine two important scale factors: the Einstein radius and the caustic crossing timescale. The Einstein radius, η, represents the microlensing scalelength in the source plane. For a single star of mass M it is given as

$$\eta = \sqrt{\frac{4GM}{c^2}\frac{D_{os}D_{ls}}{D_{ol}}}, \tag{1}$$

where D_{ij} represents the angular diameter distance between observer (o), lens (l), and source (s) (Schneider, Ehlers, & Falco 1992). For significant magnification, sources must be substantially smaller than this scalelength. Considering the cosmological distances involved, typical values of η for multiply imaged quasars, microlensed by stars of mass 1 $M_\odot$, range from $\sim$0.01-0.1 pc. The characteristic microlensing timescale, τ, is the time taken by a region of high magnification (which can be formally infinite at a 'caustic' in the magnification pattern) to sweep across a source (Kayser, Refsdal, & Stabell 1986). This is given as

$$\tau \sim \frac{f_{15}}{V_{eff}}\,\text{yr}, \tag{2}$$

where $f_{15} \times 10^{15} h_{75}^{-1}$ cm is the scalesize of the source, and

$$V_{eff} = (1+z_l)\frac{D_{os}}{D_{ol}}\frac{v_{300}}{h_{75}}\,\text{km s}^{-1} \tag{3}$$

is the effective velocity of the microlensing caustics, with z_l as the redshift of the lensing galaxy and $300v_{300}$ km s^{-1} as the velocity of the microlensing stars across the line of sight, assumed to be the bulk motion of the galaxy due to its departure from the Hubble flow. The situation is more complex when one considers motions due to the stellar velocity dispersion (Schramm et al. 1993; Wambsganss & Kundic 1995), a point which will be considered later. For macrolensed quasars, typical values of τ are around several months.

But what is the effect of microlensing on each of the scattering models discussed in Section 2? To answer this question, we need to construct, for each model, the 'view' of the central regions of the BAL quasars as seen by the microlensing caustic structure. Considering Figure 1, such a view is represented in Figure 2, which will be discussed in more detail in the following sections. With this picture, the question of how microlensing influences our view of BAL quasars can be addressed.

3.1. Model A: Scattering within the BAL Region

For this model, the enhanced polarization seen in the BAL troughs is resonance scattering within the BAL region itself. When investigating the possible microlensing effects, the size of the continuum source as seen through the scattering BAL region must be considered. Many previous studies have demonstrated that this is smaller than the typical Einstein radius by at least an order of magnitude, and hence, is subject to extreme gravitational lensing events (e.g., Lewis et

al. 1998). Similarly, as where the scattering region is the BAL region, the view of the continuum source through the BAL region in both polarized and unpolarized light will present very similar profiles.

This model is illustrated in the left-hand panel of Figure 2. The microlensing masses will see unpolarized and polarized light coming directly from the continuum source through the BAL region. Therefore, as the caustic sweeps over the BAL region, both the scattered light and absorbed light are being magnified equally. In this picture, we would expect that while microlensing results in a pronounced photometric change during a high magnification event, the observed percentage polarization in the BAL trough should remain unchanged. Similarly, if a snap-shot view were obtained of a multiply imaged BAL quasar, each image would be in a different state of microlensing, although each would possess the same polarization properties in the BAL troughs.

3.2. Model B: External Scattering

In the case of the external scattering region, we are observing light traveling two different paths as it leaves the continuum source, with the radiation which impinges on the scattering region not being significantly attenuated by the broad absorption material. As stated previously, it is necessary to take into account the size of the scattering region, which in this case is unknown. If it is too large to be affected by microlensing (i.e., larger in comparison to the Einstein radius of the microlensing stars), then the polarized flux will remain effectively constant, as the BAL quasar is being microlensed, while the continuum flux will be subject to variability. This leads to variability in the observed percentage polarization which will be seen in both the absorption lines and the continuum. However, if the region is indeed small enough to be significantly magnified then the flux in polarized light will also vary during microlensing, although there will be a delay between observed variability in the continuum and in the polarized flux. If the caustic is traveling parallel to the line connecting the continuum and the scattering region, the extent of this delay depends upon the projected separation, S, of the BAL and scattering regions, and the apparent velocity of the caustics and may be defined as,

$$\tau_{delay} \sim \frac{S}{V_{eff}}, \tag{4}$$

where V_{eff} is the effective velocity (Equation 3). To more clearly illustrate this point, the second panel of Figure 2 depicts the view which the microlensing caustics will have of the scattering region and the continuum source as seen through the BAL clouds. It is apparent that the caustic will pass over the individual regions separately, thereby producing a time delay between observed variabilities. Naturally, the value of τ_{delay} and which component leads the variability depend on the direction that the microlensing magnification map sweeps across the quasar central region.

Figure 3 schematically depicts the passing of a caustic across such a quasar source; both the continuum and scattering region are treated as being uniform disks with a radius of 0.05η and 0.5η, separated by S= 1η. The caustic sweeps first across the continuum source, then across the

scattering region resulting in the magnification fluctuations presented in the upper and middle panels of Figure 3. As pointed out earlier, the scattering region suffers a lower magnification than the continuum source due to its more extended nature. The lower panel of Figure 3 presents the fluctuation in the observed percentage polarization in the absorption line, assuming an intrinsic 10% polarization. As the continuum flux in the line is magnified there is a marked decrease in the percentage polarization as the emission from the scattering region is diluted, but later, when the strong magnification of the source has ceased, the scattering region is slightly magnified, leading to an enhancement of the percentage polarization. After the caustic has passed both sources they are equally magnified and the percentage polarization settles back to its pre-microlensed value, although the quasar image now appears brighter as it is still magnified by (in this case) 10%.

4.   A Microlensed BAL Quasar Case Study

4.1.   H 1413+117

To date, there are several confirmed gravitationally lensed BAL quasars: UM 425 (Meylan & Djorgovski 1988, 1989; Michalitsianos & Oliversen 1995); APM 08279+5255 (Irwin et al. 1998; Ellison et al. 1999a,b); HE 2149-2745 (Wisotzki et al. 1996); SBS 1520+530 (Chavushyan et al. 1997); PG 1115+080 (Weymann et al. 1980; Michalitsianos & Oliversen 1996); and H 1413+117 (Magain et al. 1988). While the results of this investigation apply to all of these subjects, we focus on H 1413+117 as it is the most studied and observed gravitationally lensed BAL quasar.

Identified in a survey of luminous quasars, H 1413+117 was found to possess four images of a z=2.55 quasar which exhibits broad absorption features, with image separations of $0\rlap{.}''77$ to $1\rlap{.}''36$ (Magain et al. 1988). While spectroscopy has revealed the presence of a number of absorption systems between z $\sim 1.4 - 2.1$, there has been no indication of a lensing system between the quasar images in ground based observations (Lawrence 1996), although the system does lie behind a cluster of galaxies at z~ 1.7 which perturbs the lensing via shearing (Kneib et al. 1998a). Recent analysis of NICMOS images of H 1413+117, however, does reveal a very faint ($H_{160W} = 20.5$), extended system at the center of the cross-like quasar image configuration (Kneib et al. 1998b).

Angonin et al. (1990) undertook integral field spectroscopy of individual images in H 1413+117. While confirming the BAL nature of the source quasar, these observations also revealed spectroscopic differences between the images, namely in the relative strength of the Si IV $\lambda\lambda$1394, 1403 and C IV λ1549 broad emission features (Hutsemékers 1993), a signature of differential gravitational microlensing by stellar mass objects in the intervening galaxy (Sanitt 1971; Lewis et al. 1998). This phenomenon has also been observed in another quadruple quasar, Q 2237+0305 (Lewis et al. 1998). Such a conclusion is supported by an observed photometric variability in H 1413+117 (Remy et al. 1996) and significant differences between the BAL profiles of the individual images (Angonin et al. 1990; Hutsemékers 1993).

There have been several investigations into the microlensing effects on BAL profiles within the spectra of the multiple images of H 1413+117. The first, which used a Chang-Refsdal Lens (Chang & Refsdal 1979, 1984) to examine the effects on an individual cloud within the BAL region, was presented by Hutsemékers (1993; Hutsemékers, Surdej, & Van Drom 1994). Although this model was able to reproduce the observed spectral variations, it required a very specific alignment of the caustic, an individual BAL cloud, and the BAL region, and even a slight change would have a significant effect on the predicted magnification. A different approach was taken in Paper I, where we considered a model for the BAL region consisting of multiple clouds with varying amounts of absorption. Although the caustic framework is rather intricate at high optical depth, the scalesizes of this and of the source quasar are such that most of the caustics crossing the BAL region will be isolated fold catastrophes (Schneider, Ehlers, & Falco 1992). This allowed a fairly simple calculation of the microlensing effects on the BAL region, and it was shown that the microlensing variability seen within the spectra of the lensed images of H 1413+117 could be reproduced if the scalesize of the BAL clouds are $\sim 10^{15}$ cm.

4.2. Event Statistics and Time Scale

An important consideration is the timescale on which microlensing events will occur. To characterize the lensing scenario, two caustic crossing timescales need to be defined: the crossing times of the continuum source and the Einstein radius. For these calculations, we assume a standard cosmology of $\Omega = 1$ and $\Lambda = 0$, and $H_0 = 75 \, \mathrm{km \, s^{-1} Mpc^{-1}}$. Using Equation 2, the timescales can all be calculated rather simply. If the continuum source is assumed to be 1×10^{15} cm (Wambsganss, Schneider, & Paczyński 1990) and the velocity of the lensing galaxy across the source plane is taken to be $300 \, \mathrm{km \, s^{-1}}$, then the crossing time of the continuum source is $\tau_{cont} \sim 0.3$ yr. The Einstein radius for the parameters pertaining to H 1413+117 is $\eta \sim 0.006 \sqrt{M/M_\odot}$ pc giving a crossing time of $\tau_{ER} \sim 6.5$ yr for a one solar mass star. If the separation, S, between the scattering region and continuum source is taken to be $S = 1\eta = 19.4 \times 10^{15}$ cm, then $\tau_{delay} = \tau_{ER} \sim 6.5$ yr.

As discussed in Section 3, the pattern of magnification that a source undergoes is rather intricate, and the positions of the caustics projected onto the source plane will obviously dictate when and how often a source will undergo a microlensing event. In order to determine the timescales on which these events will occur, it is necessary to examine the light curve of a source which results as the caustic network passes over the source. Such calculations were performed for the lensed quasar Q 2237+0305 by Witt, Kayser, & Refsdal (1993), who determined the nature of the light curve specific to the lensing parameters of each individual image. From these light curves the statistics of the microlensing events could be calculated, including the average time between high magnification events. To determine similar parameters for H 1413+117, we can extrapolate from the work of Witt, Kayser, & Refsdal (1993) (because of similarities in lensing parameters) and then scale these numbers to H 1413+117. We find that if the source is moving parallel to the shear, then a lensing event will occur every ~ 1.3 yr and if the source is moving perpendicular to the shear,

then lensing events will occur on timescales of ~ 0.9 yr. These timescales mean that *significant microlensing effects can be seen if observations are made every couple of weeks over the course of a few years.*

5. Conclusions

While current polarimetric data of BAL quasars have led to theories about the origin of the polarized light, these observations cannot clearly delineate between the various scattering models. However, as we have argued in this paper, microlensing may provide more detailed clues about the structure of the inner regions of quasars. Considering a scattering region associated with the BAL material and a scattering region separate from the BAL region as the most widely accepted scattering models, there will result three different signatures apparent in observations of a microlensed BAL quasar:

- Case 1 (Model A): There is no time delay between continuum and polarization variability and no percentage polarization change in the BALs.

- Case 2 (Model B): No time delay is observed between continuum and polarization variability but a percentage polarization change in the BALs is detected.

- Case 3 (Model B): There is a time delay between continuum and polarization variability, and a percentage polarization change is apparent in the BAL troughs.

(Note that as there is an overall enhancement in polarized flux, the percentage polarization of the continuum will also be seen to change during a microlensing event for all of these cases.) Case 1 implies that the polarization is actually associated with the absorbing material. Case 2 and 3 both suggest that the scattering region is not associated with the absorbing material, although, Case 2 indicates that the scattering region is large, while Case 3 points to a small scattering region. If Case 2 or 3 is apparent in observations of a gravitationally lensed BAL quasar, then the separation between the scattering region and the continuum source may be calculated from the observed time delay. Most importantly, observations of a single microlensing event will allow us to differentiate between the two scattering models.

In considering these models, however, it is important to also examine the effects of intrinsic variability of the AGN source which may mask any microlensing signal. Foremost is luminosity variability. Important for model B, any change in the source luminosity will manifest itself in polarized flux after a delay due to the geometric light travel distance. Such variability, however, possesses several properties that make it easily distinguishable from any microlensing induced features. Namely, that change in unpolarized flux always leads that of the polarized flux and the observed delay between the two will be the same in all images of a multiply lensed quasar. With microlensing, however, the relative phase and time delay between the unpolarized and polarized

variability depend upon the direction and velocity that a caustic sweeps across the AGN source, properties that will be different in each macrolensed image. Similarly, an observed polarization fluctuation that may be attributed to microlensing of model A could possibly be due to intrinsic variability of the polarized emission from the quasar source. As with luminosity variability, however, such intrinsic polarization variability will manifest itself in each component of a multiply imaged quasar, modulo a gravitational lensing time delay, and hence can be accounted for. The details of microlensing induced variability, however, will be unique to a particular image and will be uncorrelated with that of the other images.

Although we have presented a simple and straightforward method for using polarimetric observations of gravitationally microlensed BAL quasars to determine various parameters pertaining to the polarization, there is a degeneracy in these calculations as all of the quantities depend on the mass of the microlensing objects (as $\sqrt{M}$) and the unknown transverse velocity. This is also complicated by the fact that there may be a significant velocity dispersion within the lensing galaxy which would make the calculations outlined in this paper much more complex. Removing these degeneracies in another gravitationally lensed quasar, Q 2237+0305, has been the goal of recent studies by Wyithe (1999) and Wyithe, Webster, & Turner (1999a,b,c) who have demonstrated that monitoring gravitationally lensed quasars will lead to the determination of these unknown quantities. We plan to extend the current study presented in this paper with simulations that will more closely examine microlensing effects occurring within the multiple images of H 1413+117, and which will also consider the mass and velocity degeneracies.

REFERENCES

Alcock, C., et al. 1993, Nature, 365, 621

Angonin, M.-C., Remy, M., Surdej, J., & Vanderriest, C. 1990, A&A, 233, L5

Antonucci, R. R. 1993, ARA&A, 31, 473

Antonucci, R. R., & Miller, J. S. 1985, ApJ, 297, 621

Arav, N., & Li, Z.-Y. 1994, ApJ, 427, 700

Arav, N., Li, Z.-Y., & Begelman, M. C. 1994, ApJ, 432, 62

Brandt, W. N., Comastri, A., Gallagher, S. C., Sambruna, R. M., Boller, T., & Laor, A. 1999, ApJ, 525, 69

Chang, K., & Refsdal, S. 1979, Nature, 282, 561

Chang, K., & Refsdal, S. 1984, ApJ, 132, 168

Chavushyan, V. H., Vlasyuk, V. V., Stepanian, J. A., & Erastova, L. K. 1997, A&A, 318, L67

Cohen, M. H., Ogle, P. M., Tran, H. D., Vermueulen, R.C., Miller, J. S., Goodrich, R. W., & Martel, A. R. 1995, ApJ, 448, L77

Corrigan, R. T., et al. 1991, AJ, 102, 34

Ellison, S. L., Lewis, G. F., Pettini, M., Sargent, W. L. W., Chaffee, F.H., Foltz, C. B., Rauch, M., & Irwin, M. J. 1999a, PASP, 111, 946

Ellison, S. L., Lewis, G. F., Pettini, M., Sargent, W. L. W., Chaffee, F.H., & Irwin, M. J. 1999b, ApJ, 520 456

Fluke, C. J., & Webster, R. L. 1999, MNRAS, 302, 68

Gallagher, S. C., Brandt, W. N., Sambruna, R. M., Mathur, S., & Yamasaki, N. 1999, ApJ, 519, 549

Goodrich, R. W., & Miller, J. S. 1995, ApJ, 448, L73

Hines, D. C., & Wills, B. J. 1995, ApJ, 448, L69

Hutsemékers, D. 1993, A&A, 280, 435

Hutsemékers, D., Surdej, J., & Van Drom, E. 1994, A&AS, 216, 361

Irwin, M. J., Hewett, P. C., Corrigan, R. T., Jedrzejewski, R. I., & Webster, R. L. 1989, AJ, 98, 1989

Irwin, M. J., Ibata, R. A., Lewis, G. F., & Totten, E. J. 1998, ApJ, 505, 529

Kayser, R., Refsdal, S., & Stabell, R. 1986, A&A, 166, 36

Kneib, J.-P., Alloin, D., Mellier, Y., Guilloteau, S., Barvainis, R., & Anotnucci, R. 1998a, A&A, 329, 827

Kneib, J.-P., Alloin, D., & Péllo, R. 1998b, A&A, 339, L65

Kuncic, Z. 1999, PASP, 111, 954

Lawrence, C. R. 1996, in *IAU Symp. 173: Astrophysical Applications of Gravitational Lensing*, Eds. Kochanek, C. & Hewitt, J., Kluwer

Lewis, G. F., & Belle, K. E. 1998, MNRAS, 297, 69 (Paper I)

Lewis, G. F., & Ibata, R. A. 1998, ApJ, 501, 478

Lewis, G. F., & Irwin, M. J. 1995, MNRAS, 276, 103

Lewis, G. F., & Irwin, M. J. 1996, MNRAS, 283, 225

Lewis, G. F., Irwin, M. J., Hewett, P. C., & Foltz, C. B. 1998, MNRAS, 295, 573

Lewis, G. F., Miralda-Escudé, J., Richardson, D. C., & Wambsganss, J. 1993, MNRAS, 261, 647

Magain, P., Surdej, J., Swings, J.-P., Borgeest, U., Kayser, R., Kühr, H., Refsdal, S., & Remy, M. 1988, Nature, 334, 325

Meylan, G., & Djorgovski, S. 1988, ESO Messenger 54, 39

Meylan, G., & Djorgovski, S. 1989, ApJ, 338, L1

Michalitsianos, A. G., & Oliversen, R. J. 1995, ApJ, 439, 599

Michalitsianos, A. G., & Oliversen, R. J. 1996, ApJ, 461, 593

Murray, N., Chiang, J., Grossman, S. A., & Voit, G. M. 1995, ApJ, 451, 498

Nemiroff, R. J. 1988, ApJ, 335, 381

Ogle, P. M. 1997, in *Mass Ejection from Active Galactic Nuclei*; ASP Conference Series 128, Eds. Arav, N., Shlosman, I. & Weymann R. J., 78

Remy, M., et al. 1996, in *IAU Symp. 173: Astrophysical Applications of Gravitational Lensing*, Eds. Kochanek, C. & Hewitt, J., Kluwer

Sanitt, N. 1971, Nature, 234, 199

Schmidt, G. D., & Hines, D. C. 1999, ApJ, 512, 125

Schneider, P., Ehlers J., & Falco, E. E. 1992, Gravitational Lenses. Springer-Verlag, Berlin

Schneider, P., & Wambsganss, J. 1990, A&A, 237, 42

Schramm, T., Kayser, R., Chang, K., Nieser, L., & Refsdal, S. 1993, A&A, 268, 350

Scoville, N., & Norman, C. 1995, ApJ, 451, 510

Shields, G. A. 1996, ApJ, 461, L9

Shields, G. A. 1997, in *Mass Ejection from Active Galactic Nuclei*; ASP Conference Series 128, Eds. Arav, N., Shlosman, I. & Weymann R. J., 214

Sprayberry, D., & Foltz, C. B. 1992, ApJ, 390, 39

Turnshek, D. A. 1984, ApJ, 280, 51

Turnshek, D. A. 1986, in *I.A.U. Symp. 119: Quasars*, Eds. Swarup, G. & Kapahi, V. K., D. Reidel Publishing Company, 317

Turnshek, D. 1988, in *QSO Absorption Lines: Probing the Universe*, Eds. Blades J. C., Turnshek D. & Norman, C. A., Cambridge University Press

Turnshek, D. 1995, in *QSO Absorption Lines, ESO Workshop*, Ed. G. Meylan, Springer Press

Wambsganss, J. 1990, PhD thesis, MPA, München

Wambsganss, J., & Kundic, T. 1995, ApJ, 450, 19

Wambsganss, J., Schneider, P., & Paczyński, B. 1990, ApJ, 358, L33

Weymann, R. 1995, in *QSO Absorption Lines, ESO Workshop*, Ed. G. Meylan, Springer Press

Weymann, R. J., Latham, D., Angel, J. R. P., Green, R. F., Liebert, J. W., Turnshek, D. E., & Tyson, J. A. 1980, Nature, 285, 641

Wisotzki, L., Köhler, T., Lopez, S., & Reimers, D. 1996, A&A, 315, L405

Witt, H.-J. 1993, ApJ, 403, 530

Witt, H.-J., Kayser, R., & Refsdal, S. 1993, A&A, 268, 501

Wyithe, J. S. B. 1999, in *Gravitational Lensing: Recent Progress and Future Goals*, ASP conference series, eds. Brainerd & Kochanek, C. (astro-ph/9909358)

Wyithe, J. S. B., & Webster, R. L. 1999, MNRAS, 306, 223

Wyithe, J. S. B., Webster, R. L., & Turner, E. L. 1999a, MNRAS, submitted (astro-ph/9901339)

Wyithe, J. S. B., Webster, R. L., & Turner, E. L. 1999b, MNRAS, 309, 261

Wyithe, J. S. B., Webster, R. L., & Turner, E. L. 1999c, MNRAS, submitted (astro-ph/9904359)

Yonehara, A. 1999, ApJ, 519, L31

Yonehara, A., Mineshige, S., Fukue, J., Umemura, M., & Turner, E. L. 1999, A&A, 343, 41

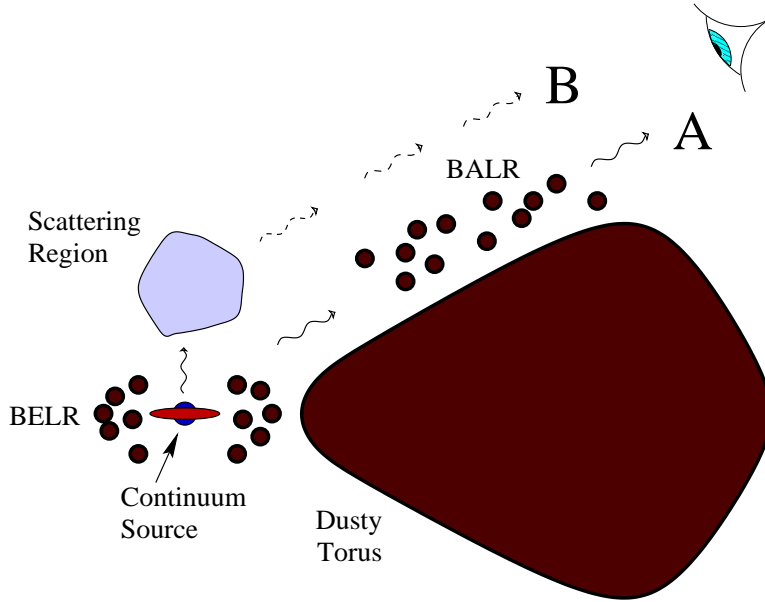Yonehara, A., Mineshige, S., Manmoto, T., Fukue, J., Umemura, M., & Turner, E. L. 1998, ApJ, 501, L41

Fig. 1.— A schematic representation of the current standard model for quasars exhibiting broad absorption features. Here, the BAL material is ablated from the surface of the dusty torus. Two sources for the observed polarization characteristics are postulated; i) radiation from the continuum source is intrinsically polarized. While traveling through the BAL absorption region (path **A**), this is enhanced by the action of resonance scattering of emission into the line of sight. ii) the continuum source is not necessarily polarized, but continuum radiation is polarized by impinging on a region of electrons and dust and being scattered into the line of sight (path **B**). With this, the enhanced polarization seen in the BAL troughs is due to the reduced unpolarized flux, while the polarized flux remains relatively free of absorption.
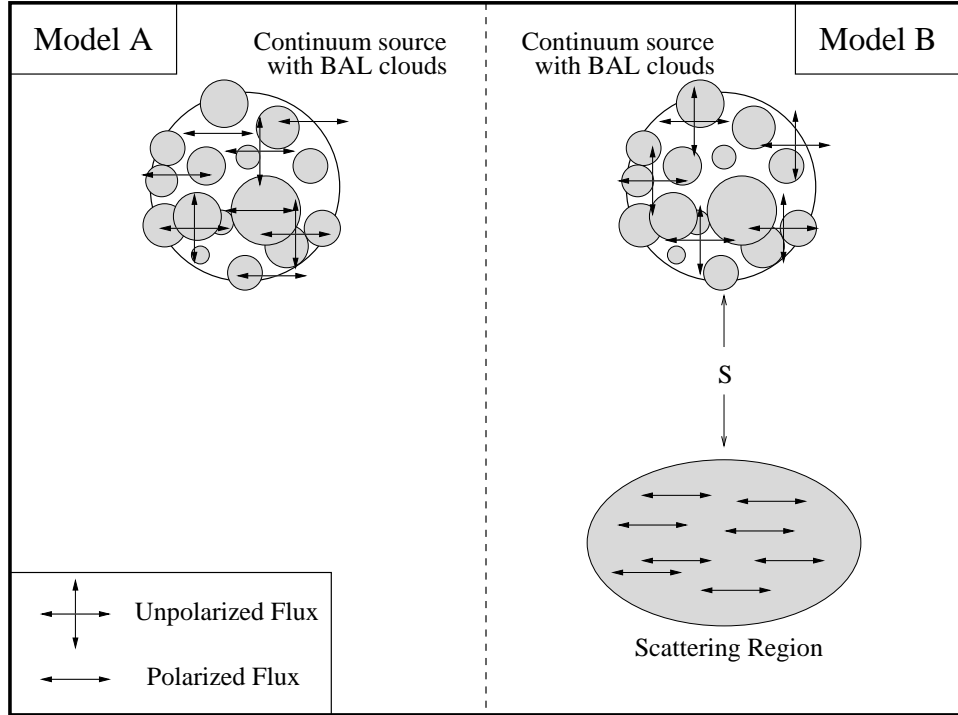
Fig. 2.— The view of the BAL quasar continuum and scattering region as seen by the microlensing caustic for both scattering scenarios. The first panel shows Model A, in which resonance scattering within the BAL region causes the polarization of the continuum flux. The second panel presents Model B, where polarization is due to a scattering region separated by a distance, S, from the continuum source and BAL region.
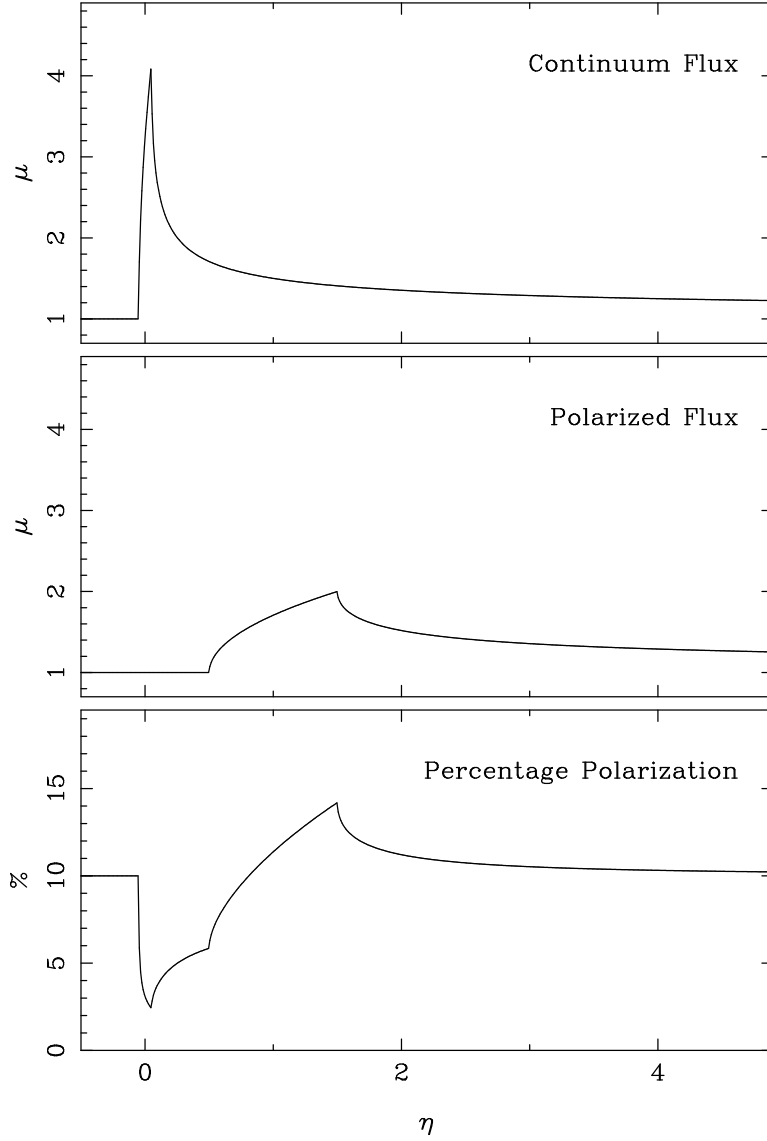
Fig. 3.— An example of the fluctuation in percentage polarization in a broad absorption line trough as a caustic sweeps across the source model B (bottom panel). Here, the caustic sweeps first across the small continuum/BAL source (top panel), then over a more extended scattering region which is responsible for the polarized flux (middle panel), with each panel presenting the magnification of the source. The sharp changes in both the magnification curve, and hence the observed percentage polarization variability, reflect the abrupt edges in the assumed source model of a uniform disk. The x-axis is in units of Einstein radii.